# A HEIGHT AND STRENGTH ANALYSIS OF THE MARINE BOUNDARY LAYER OFF THE CALIFORNIA COAST

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OC3570 Cruise Project

## 1. Introduction

The Coast of California is marked by a distinct marine boundary layer. A relatively well-mixed lower layer, with rapidly increasing temperature and rapidly decreasing moisture, characterizes this marine boundary layer or inversion. The inversion is formed by a combination of subsidence, or sinking of air, produced by the Eastern Pacific High (EPH), and cooling from below by the cold pacific waters. Its strength and height are influenced by many factors, including synoptic scale pattern changes and coastal effects such as sea breezes and coastal jets. These unique influences are what brings us our microclimate here in Monterey and what brings many people to this peninsula area each year.

In the summer, the Eastern Pacific High is very strong, around 1020-1030 milibars and is positioned further north. This increases the subsidence and thus, the adiabatic warming aloft. A strong northwesterly wind results from this unique synoptic weather pattern. This northwesterly wind causes a phenomenon known as the Ekman transport. The Ekman transport causes the upper layer of water along the coast of California to be transported offshore. This water is then replaced by upwelling water from below which is much cooler than the water it replaced. This combination of increased subsidence and upwelling along the coast creates an inversion that is generally much stronger in the summer time. This strong inversion traps cool, moist air close to the surface, which is the reason why much of the California coastline is blanketed by a thick stratus or fog layer for many hours each day in the summer.

In the winter the opposite occurs. The inversion is much weaker in the winter months. Subsidence is not as strong since the EPH is further south, and the air sea temperature difference is much less. This is because there is a lack of upwelling and the air is much cooler. The synoptic pattern is more variable as mid-latitude cyclones transit this region in the wintertime. As a result the inversion is a much different phenomenon to study in the winter season.

## 2. Measurements

Measurements for this analysis were made during both legs of the OC3570 2004 summer cruise on board the R/V Point Sur. The first leg occurred from Aug 4$^{th}$ to the 7$^{th}$ and the second occurred from Aug 8$^{th}$ to Aug 11$^{th}$. The cruise data consisted of time and position information collected from GPS receivers onboard, rawinsonde soundings, and meteorological conditions recorded on the underway data acquisition system (UDAS). The data was collected as the ship transited in the Monterey Bay and along the California coast to the Channel Islands. The Ship made its way south stopping to take frequent measurements along the way. The positions of the measurements were along CALCOFI lines. The first leg began at line 67, went to 70, and ended with line 77 on the 7$^{th}$, in Port San Luis. Measurements continued on the 7$^{th}$ as the ship departed and began again on CALCOFI line 70 ending with CALCOFI line 85 near the coastline just south of Santa Catalina Island. Used in this study were NOGAPS 1km analysis fields, GOES 10 1km and 4km resolution visual satellite images, hourly ship and buoy station observations, upper air soundings from Vandenberg and Oakland. All data was collected via the Naval Postgraduate School (NPS) Meteorology Department.

### 3. Data Processing

Rawinsonde printouts were generated on the ship during balloon launch using an MRS system onboard. These printouts where used for initial analysis while underway. For a more detailed look at the soundings the data was processed and viewed graphically using MATLAB. Specific and detailed MATLAB code had to be generated that allowed the raw data to be processed for analysis. The initial processing was done to display the plots as a temp in degrees Celsius verses Height. This was done for both Temperature and Dew Point Temperature. Since the study involved not only strength, but also height of the boundary layer the data was further processed to show a spatial relationship with respect to Boundary layer height. To show this spatial relationship a 3d contour code was generated using MATLAB. The code enabled the plotting of the heights verses the coastline showing altitude offshore of the inversion height. During processing the coastline was held at 0 m allowing the boundary height to be placed at altitude on the Z axis. NOGAPS fields, observations, and satellite images were processed, displayed, and analyzed using GARP software in the Meteorology Department's computer laboratory (IDEA LAB). The Naval Postgraduate School Meteorology department's website was also used to find and view the Vandenberg and Oakland soundings in skew-t format.

## 4. Synopsis

During the end of the first leg of the cruise as the Point Sur pulled into Port San Luis the inversion was strengthening. Going from barely noticeable to a very strong inversion. On Aug 7$^{th}$ as the ship departed Port San Luis the inversion was again weak and not very well defined. However, this was short lived, as the ship headed out to finish the CALCOFI lines it was very apparent to all onboard the inversion had returned and would influence the weather for the next three days. By the 11$^{th}$ the inversion had begun to lose its strength, as we made our way east just south of the Channel Islands.

## 5. Discussion

The synoptic pattern at 0000 UTC on Aug 7$^{th}$ showed a 1022 mb EPH centered to the west of San Diego. A relatively strong 990 mb low pressure system was approaching Washington and Oregon states riding over the top of the EPH which would keep it well north of California. This type of synoptic situation is very typical for the summer months along the west coast of the United States.

(See slide 4 of the accompanying power point presentation). A very strong subsidence inversion was beginning to form at about 178 m as shown in blue color by rawinsonde 12 at 0540 UTC just west of Port San Luis as the Point Sur made its way toward the coast. The inversion continued to strengthen through out the day as the ship neared shore. The inversion went from 3.9 °C to a very strong 12.4 °C over the next 16 hours of the transit. The strength of the inversion at 2100 UTC on the 7th would prove to be one the strongest inversions seen on the entire cruise. This is depicted in red on (Fig. 1).

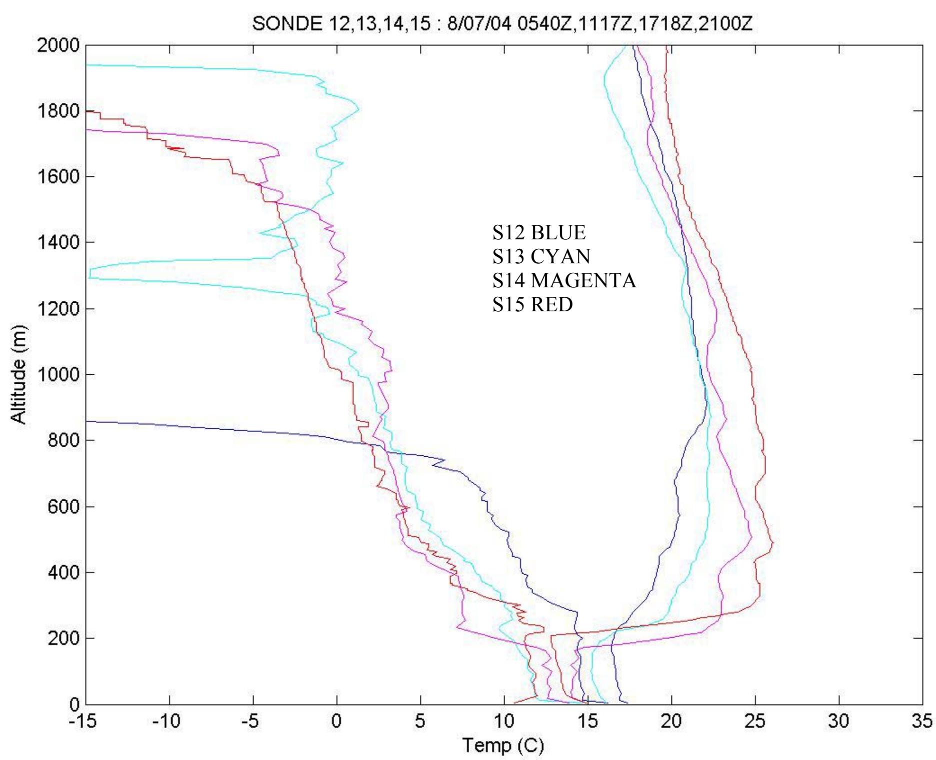


**Figure 1: Rawinsonde 12,13,14,15**

As the thermal gradient increased the height of the inversion began to become much more defined and established. The height went from 154 m to 207 m and went from a weak 309 m thickness to 129 m thickness over a 12.4 ℃ change in temperature.  This equates to about a 9 ℃ / 100 meter change.  This strength can be seen in Rawinsonde 15 (Fig. 1) and the inversion height variance can be seen in (Fig. 2). Rawinsonde 15 was launched at about 10-15 nm west of Port San Luis and is shown in (Fig. 2) as a red stick.

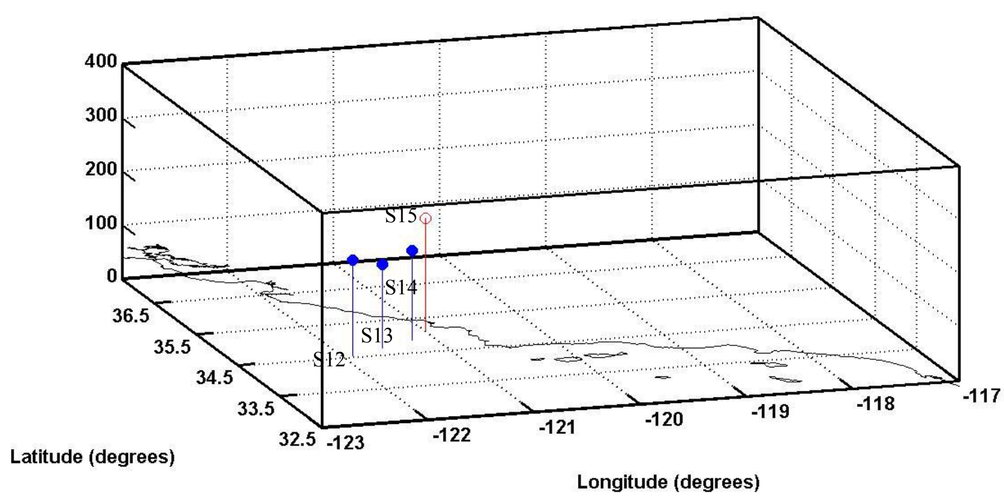


**Figure 2: Rawinsonde 12,13,14,15**

By 0000 UTC on the 8th, the inversion had weakened and re-intensified.  As the Point Sur headed back out on the

CALCOFI line the inversion had lowered again to about 78 m, this occurred around 0232 UTC on the 8th. Winds along this course remained out of the North West at the surface for the entire leg. This wind direction was recorded on board using the UDAS system and was also shown in the Vandenberg sounding (Fig. 3). Looking into the Vandenberg sounding more closely we can the winds are veering with height. Winds veering with height are an indicator of warm air advection (WAA). This WAA can strengthen the boundary layer by providing more warm air aloft. The advection of warm air can also affect the height of the boundary layer by increasing mixing near the surface and raising the height.

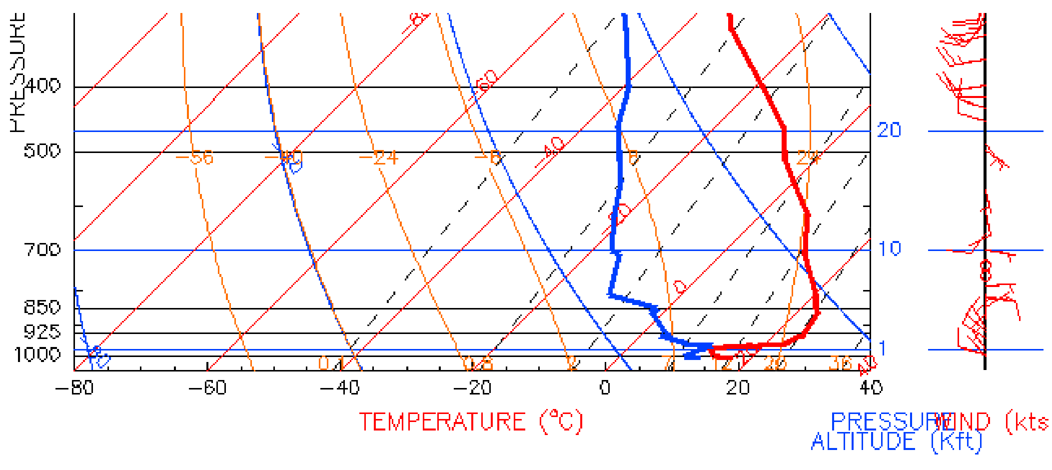


**Figure 3: Sounding for Vandenberg 0000 UTC 8/08/2004**

As the ship made its way out of port the inversion began to reestablish it self and would once again become very strong. This time the inversion would reach a strength of about 13 °C / 100 meter change in height on Rawinsonde 17 this occurred at about 0354 UTC, again at about 10-15 nm offshore (Fig. 4).

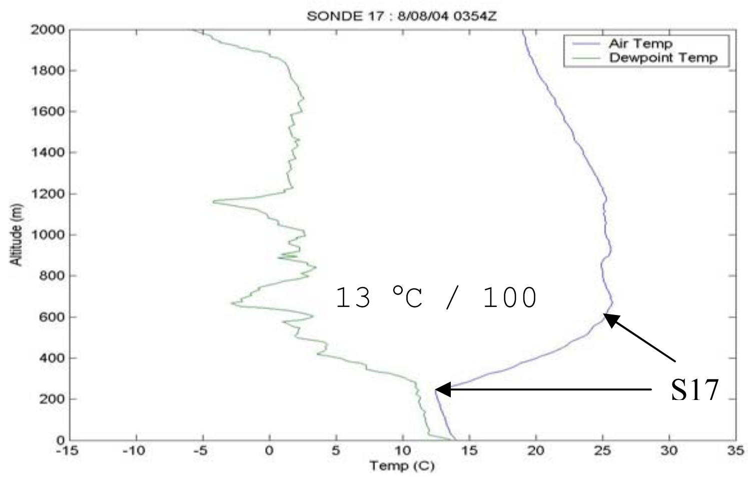


**Figure 4: Rawinsonde 17**

The inversion height went from about 78 m to 359 m (Fig. 5) along this track, and the strength of the inversion varied from 8.1 °C to 13 °C From Rawinsonde 16 to Rawinsonde 19 (Fig. 6).

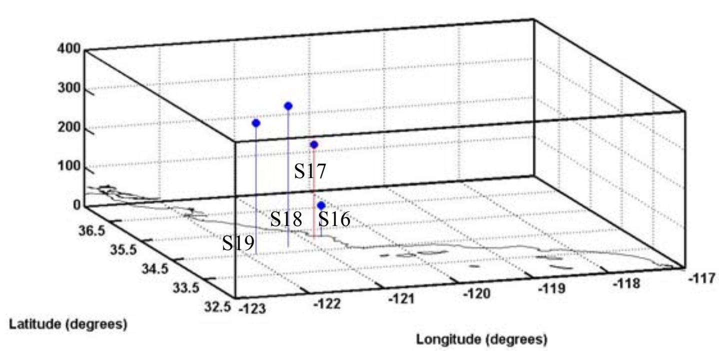

**Figure 5: Rawinsonde 16,17,18,19**

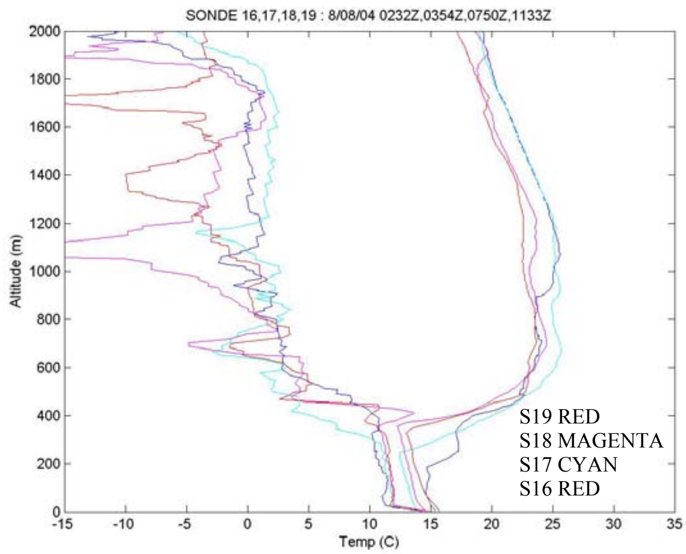


**Figure 6: Rawinsonde 16,17,18,19**

Rawinsonde 17 can be seen in Figure 6 as a Cyan colored line and can be seen in Figure 5 as a red stem on the 3d plot. These two plots when combined begin to show the spatial and temporal changes of the Marine Boundary Layer. Along with visual imagery one begins to see the true aspect of this very strong inversion that caps the lower layers of the atmosphere off the coast of California (Fig. 8).

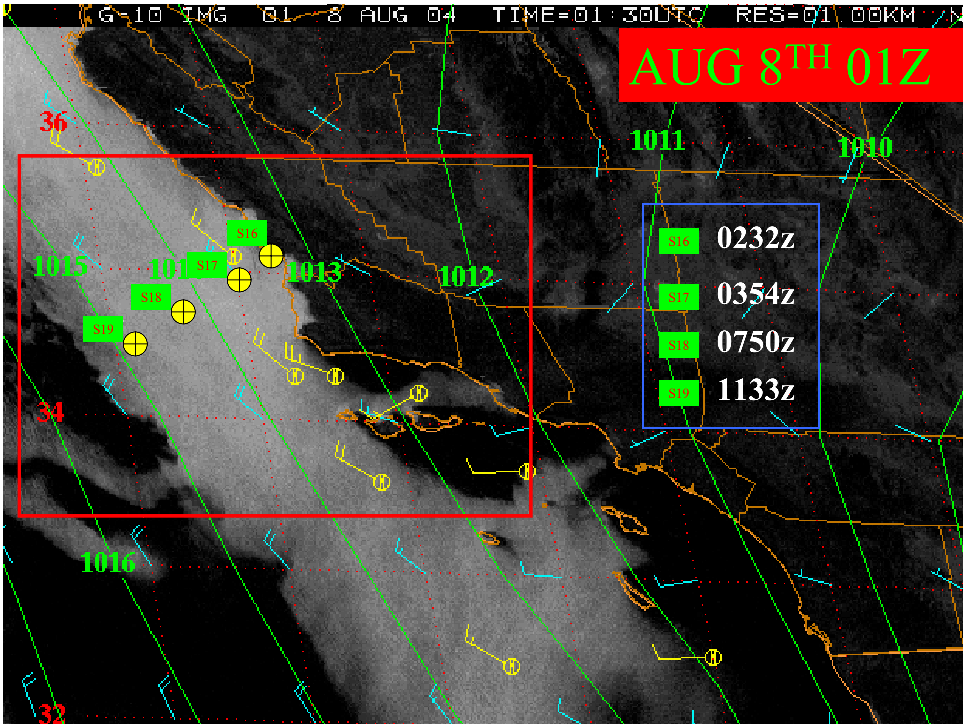


**Figure 8: 1km Visual SAT PIC 0130 UTC 8 AUG 04**

As seen above the Marine boundary layer was well established for our transit south. The next Rawinsonde we launched was S21; it was launched 12 hours after Rawinsonde 19. Assuming that we made about 8kts good per hour I estimated that we launched S21 about 80-90 nm south of Rawinsonde 19. Rawinsonde 20 was a Kite Sonde and will not be used for purposes of this study. Rawinsonde 21 was sent up at 2327 UTC on the 8th of August. Its position was 33-31N 121-38W. This Rawinsonde had an inversion height of about 459 m and strength of about 10 °C. This particular sounding turned out to be unique because of the very distinct and sharp temp increase along with the very distinct and sharp decrease in Dew Point temperature. This Rawinsonde is very typical of a sounding taken under the Marine layer (Fig. 9).

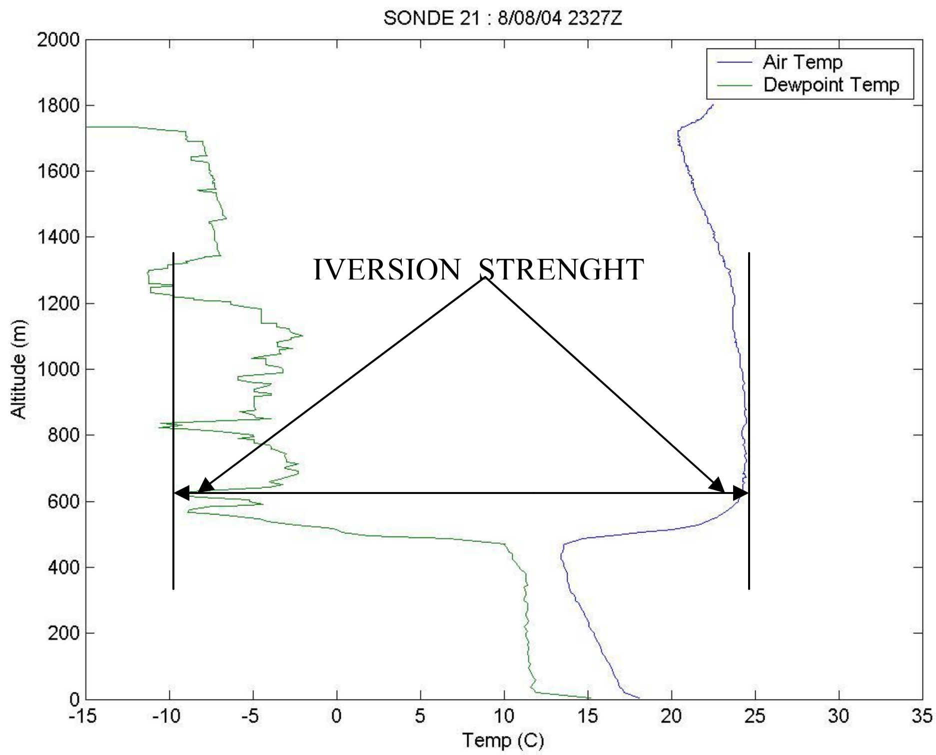


**Figure 9: Rawinsonde 21**

Rawinsondes 22,23,24,25 were launched heading back in from CTD station #42 at the end of CALCOFI line "70s" and at the beginning of CALCOFI line 85. These next four soundings showed the inversion height ranging from 207 m to 552 m, and a temperature range of about 12-16 °C. This change is a spatial change since we where heading east this entire leg. The time span for these four launches was 32 hours (Fig. 10).

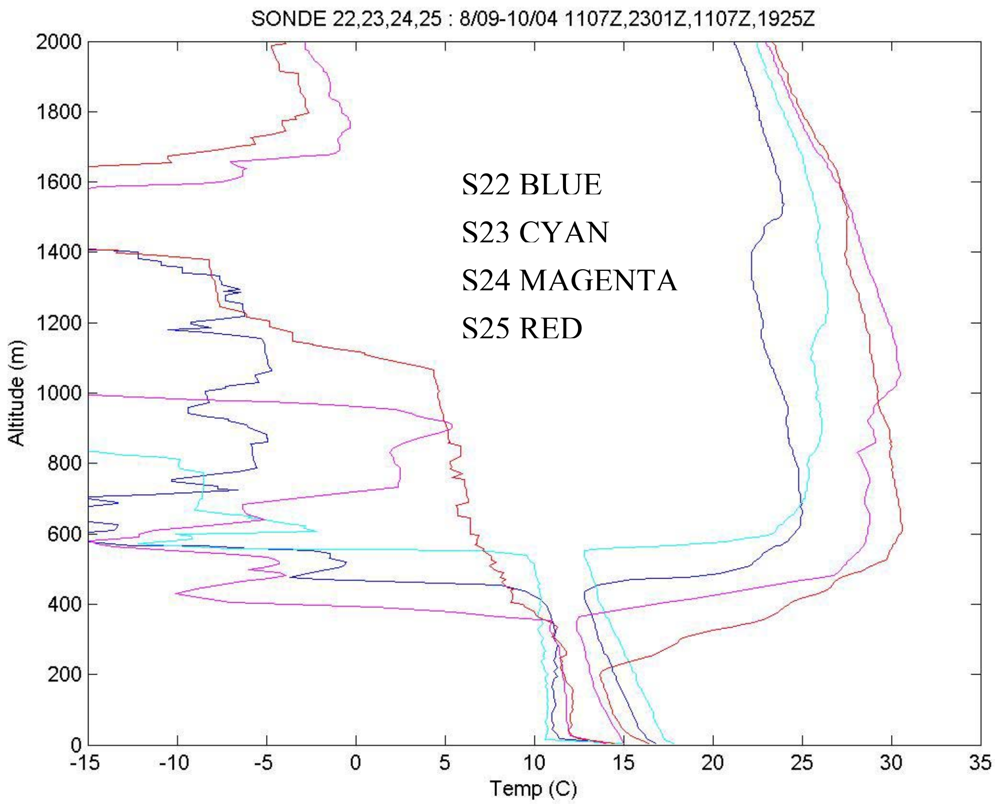


**Figure 10: Rawinsonde 22,23,24,25**

Figure 11 shows the Boundary Layer Height Variance as the ship made its transit toward the east.

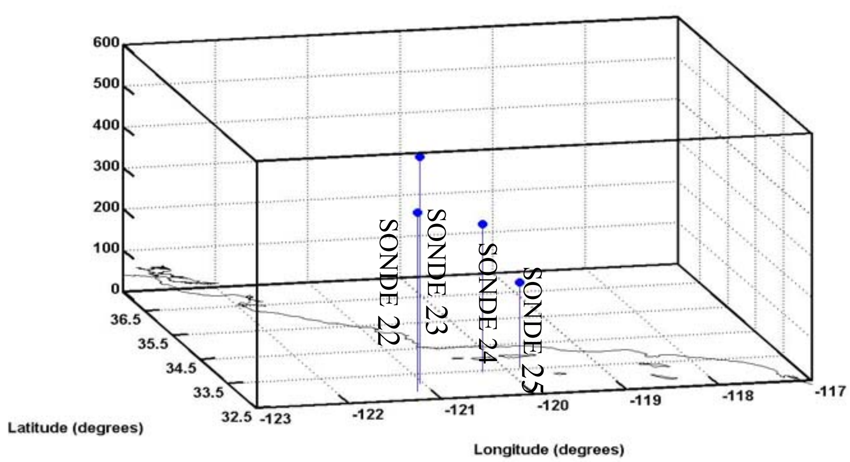

**Figure 11: Rawinsonde 22,23,24,25**

As we made our way east the weather began to lift out (Fig. 12) and we launched the last of our balloons over the next 6 hours. These launches where marked by a significant decrease in the Marine layer that went from 102 m to about 78 m (Fig 13).  The intensity ranged from 10-13 °C (Fig. 14).

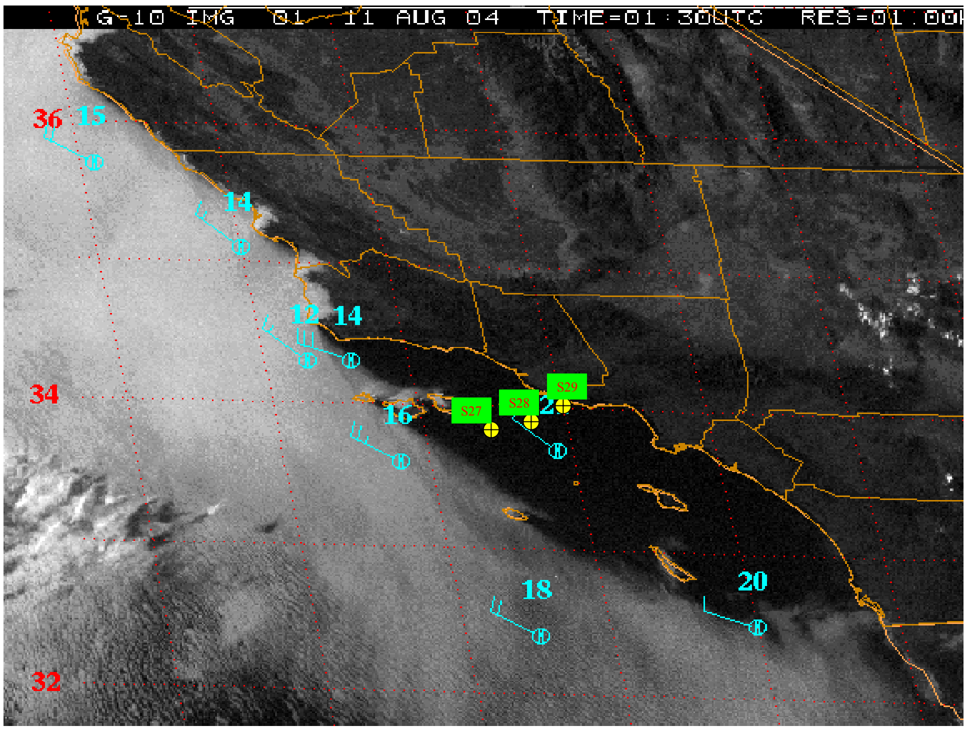


**Figure 12: 1km Visual SAT PIC 0130 UTC 11 AUG 04**

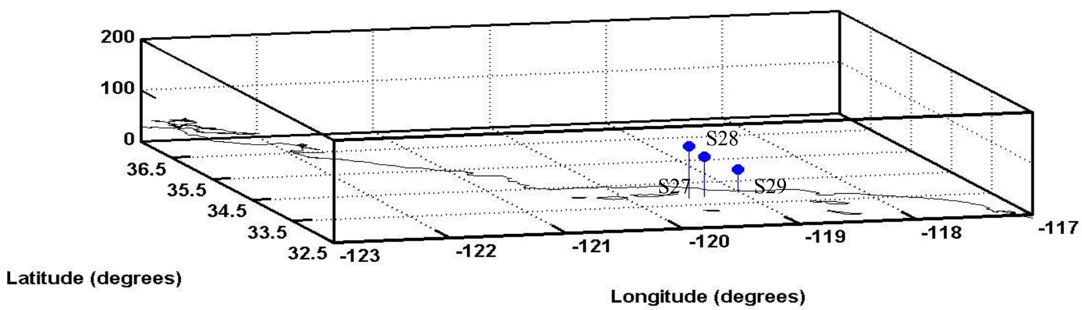


**Figure 13: Rawinsonde 27, 28, 29**

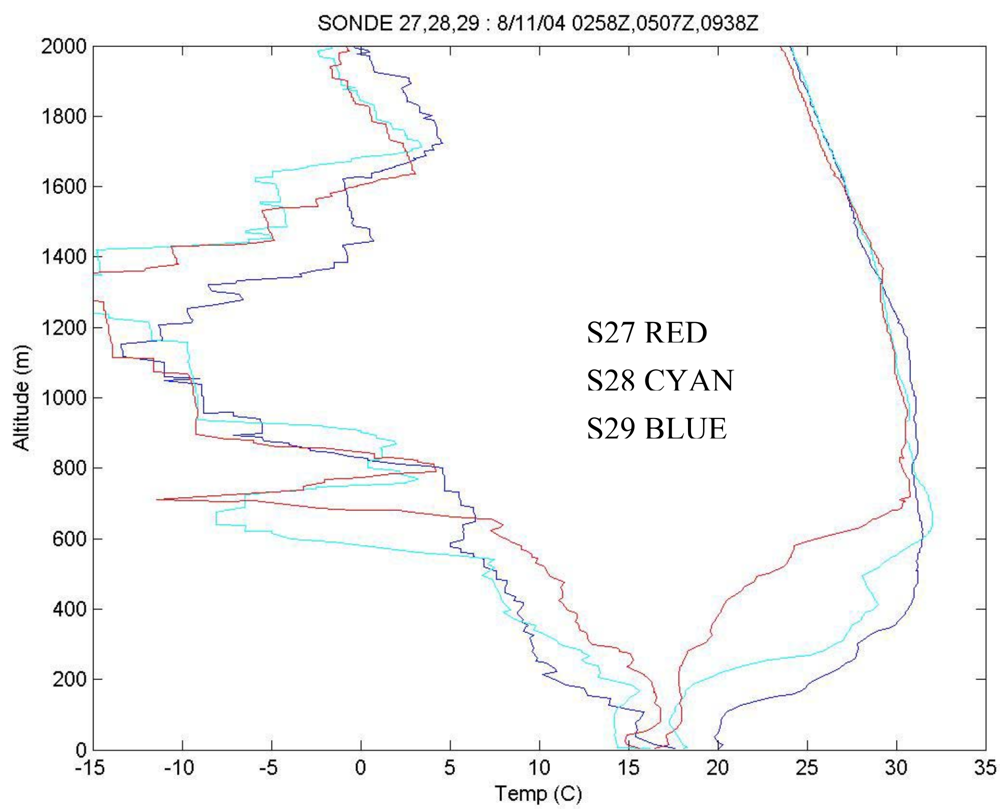

**Figure 14: Rawinsonde 27, 28, 29**

## 6. Conclusions

The OC3570 summer cruise proved to be very interesting however, not a very dynamic period meteorologically. The effect of the synoptic weather situation had little effect on the marine boundary layer inversion. The inversion remained throughout the period of the cruise. It did however, decrease and increase in strength and decrease and increase in height. These fluctuations were some times significant and lasted for a couple of days. They generally could be attributed to the position of the ship and whether or not there was a stratus deck. Both times the ship approached the coastline we were able to see that the inversion height decreased. This was most noticeable on the 3D plots that were generated using MATLAB. These plots were able to show both the spatial and temporal changes in the dynamic height of the inversion. I believe that this study could have been more interesting had there been a transiting low in our OPAREA during the transit south.